IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s):	Clark, Steven A. Pillai, Balathandan S.
Title:	METAL ALLOY PRODUCT AND METHOD FOR PRODUCING SAME
Application No.:	09/656,626
Filing Date:	09/07/2000
Examiner:	Combs-Morillo, Janell A.
Art Unit:	1742
Attorney Docket No.:	043420-0118

Commissioner for Patents
PO Box 1450
Alexandria, Virginia 22313-1450

SUPPLEMENTAL DECLARATION

I, Arvin Montes, Ph.D., declare and say as follows:

1. I submit this declaration in support of the above-identified application for a U.S. patent and in support of the Applicants' response to the Final Office Action issued on February 7, 2003 (the "Final Office Action"). This declaration supplements my earlier declaration submitted to the PTO in this application on July 11, 2003.

2. I received a B.Sc. in Mechanical Engineering from Marquette University in 1994 and a Ph.D. in Materials Science Engineering from Marquette University in 2001. For the past two and one-half years, I have been employed as a Senior R&D Materials Science Engineer at Johnson Brass & Machine Foundry, Inc. My professional experience

has involved work related to the development, manufacturing and testing of materials made from a variety of cast and wrought alloys.

3. In preparing this declaration, I have reviewed the above-identified patent application, the claims currently pending in the application, the Final Office Action issued on February 7, 2003, and the U.S. patents and other references cited in the Final Office Action.

4. The most significant difference between a centrifugal casting and a wrought product is the isotropic properties of the centrifugally cast material. Because aluminum centrifugal castings exhibit an equiaxed grain structure, one can expect properties to be independent of orientation. The results presented in my Declaration filed on July 11, 2003, for centrifugally cast 6061-T6 aluminum and 7075-T6 aluminum illustrates the isotropic nature of the centrifugally cast products. Mechanical properties, fracture toughness properties, and microstructures were investigated to illustrate the isotropic behavior of the centrifugally cast material. In contrast to the centrifugally cast material, wrought 6061-T6 and 7075-T6 materials show inherent anisotropic behavior due to the hot working process these materials have been subjected to.

5. Ideally, recrystallization will produce a completely equiaxed grain structure, e.g., the type of grain structure which can be produced by recrystallization in fully annealed alloys which have been heat treated for prolonged time at high temperatures. Due to non-uniform deformation during the working process, however, recrystallization will initiate at regions of high deformation, while regions that underwent less deformation will undergo recrystallization later. The dependence of recrystallization initiation on location within the work-piece leads to variations in the grain size of the final product. Thus, the grain structure in wrought and recrystallized aluminum alloys will have non-uniform and/or non-equiaxed grain structure irrespective of the aluminum alloy composition due to non-uniform nucleation. Therefore, one skilled in the metallurgical art would expect wrought and recrystallized 2000, 4000, 6000, 7000 and 8000 series aluminum alloys to have non-uniform and/or non-equiaxed grain structure.

Table 1.

Comparison of Physical Properties of 6061-T6 and 6061-O Aluminum Alloys.

Property	6061-T6	6061-O
% Elongation	12 %	30 %
Tensile Strength	45 KSI	18 KSI
Yield Strength	40 KSI	8 KSI

6. Wrought aluminum alloys can be converted into a fully annealed state ("O-temper") by heat treating the alloy at a relatively high temperature for a sufficient time, which may ideally produce a substantially equiaxed grain structure. Such heat treatment substantially increases the ductility of the material but dramatically decreases the strength of the alloy. For example, 6061 aluminum alloy can be fully annealed by heat treating at about 775°F (410-415°C) for 2-3 hours to produce an alloy material with a substantially equiaxed grain structure. If such a material had been subjected to wrought working, it would be expected to have a non-uniform grain structure, i.e., the regions which had been subjected to more severe deformation during cold/hot working would be expected to have a larger grain structure than other regions which had been subjected to lower degrees of deformation. Moreover, the effect of such an annealing treatment ("O-temper") on the physical properties of a 6061 aluminum alloy is illustrated in Table 1 above. For comparison purposes, the corresponding properties of a T6-temper 6061 aluminum alloy are also shown. The results demonstrate that heat treating the aluminum alloy to achieve a fully annealed state results in a substantial decrease in the strength properties of the alloy.

7. The wrought process is known to possess a high degree of anisotropy, stemming from numerous variables in the wrought process. The largest variation is a result of the existence of a primary direction of working. Deformation is not equal in all directions, resulting in anisotropic properties. Ideally, recrystallization will yield an equiaxed grain structure. Recrystallization and the final grain structure, however, depend on the amount of prior deformation, temperature of the work-piece, and time at temperature. Depending on the size of the work-piece, tooling for the different wrought processes, *e.g.* rolling, extruding, forging, differ significantly and thus, the heat transfer characteristics. Two important variables in all wrought processes include friction and temperature variations. Temperature variations can be associated with heat generated from deformation of the metal and heat loss during the hot working process. These two variables play a significant role in the variation in properties from the surface of the work-piece to the center of the work-piece.

8. One skilled in the art of metal forming would expect deformation during the wrought process to be non-uniform. For example, Dieter (Mechanical Metallurgy, 3rd Ed.; 1986) offers the following description of the non-uniformity in hot worked pieces:

> "...the structure and properties of hot-worked metals are generally not so uniform over the cross section as in metals which have been cold-worked and annealed. Since the *deformation is always greater in the surface layers*, the metal will have a finer recrystallized grain size in this region. Because the interior will be at higher temperatures for longer times during cooling than will be the external surfaces, grain growth can occur in the interior of large pieces, which cool slowly from the working temperature." (Dieter, Pg. 527)

Brick (Structure and Properties of Engineering Materials, 4th Ed.) offers the following description of the wrought process:

> "...upon cold rolling, deformation is greater in the surface zones in contact with the rolls, particularly in the early stages of deformation.... The opposite is true of hot working. Since the rolls or other working surfaces are usually cooler

than the metal, the surface layers of the metal become cooler and harder. Therefore, *deformation is greater in the center*…" (Brick, Pg. 88)

Due to the complexity of the wrought process, it is not uncommon to find differing descriptions of the grain structure following hot working. It is important to note, however, that both Dieter and Brick mention the variations and dependence of the grain structure on the variation in temperature of both the work-piece and the tooling.

9. The standard practice for reporting tensile properties of wrought aluminum products is to report values in more than one orientation. Tensile properties are reported in different orientations due to the "directional properties" resulting from the wrought process. (Hatch, Pg. 375) The variation in mechanical properties is more pronounced for larger section thicknesses. Typically, tensile properties are reported for the following orientations: longitudinal (direction of working), long transverse, and short transverse. For work-pieces with a circular cross-section, the following orientations are typically reported: tangential, axial, and radial.

10. In terms of tensile properties, ductility or percent elongation of wrought worked pieces typically exhibits the largest variation when comparing two different orientations. Significant variations in strength, however, are also observed with an increase in thickness. In order from highest ductility to lowest ductility is the following ranking: longitudinal (tangential), long transverse (axial), and short transverse (radial). A similar ranking has been observed in other properties such as fracture toughness. Table 2 illustrates the variation in tensile properties with orientation for three different forms of 6061-T6 aluminum alloy. The centrifugally cast 6061-T6 exhibits very low variation between the two orientations, suggesting that the material is isotropic. In comparison, both the forging and the plate materials exhibit varying degrees of anisotropy. The variation in mechanical properties with orientation is considerably greater for the thicker material reported by Chu and Wacker.

Table 2.
Mechanical Property Comparison of Centrifugally Cast 6061-T6 Aluminum and Wrought 6061-T6XX Aluminum.

Orientation	6061-T6 Centrifugal Casting (21" O.D. x13" I.D. x12" L)			6061-T652 9"x24"x24" Forging (Chu & Wacker)			6061-T651 Plate (1.24" thickness)		
	UTS (ksi)	YS (ksi)	%EL	UTS (ksi)	YS (ksi)	%EL	UTS (ksi)	YS (ksi)	%EL
Tangential or Longitudinal (Working Direction)	45.5	41.1	9.0	43.0	37.8	15.0	44.9	42.2	16.5
Axial or Long Transverse	45.7	41.1	9.5	45.3	39.3	11.5	44.9	40.4	15.2
Standard Deviation between Orientations	0.1	0.0	0.35	1.6	1.1	2.5	0	1.3	0.9

11. The data shown in Table 2 does not include tensile properties in the short transverse or radial direction. Due to the difficulty in extracting test specimens, data is rarely obtained in the short transverse or radial direction. The dimensions of Chu and Wacker's 6061-T6 forging, however, were large enough to extract samples in the short transverse direction. Mechanical property results for Chu and Wacker's material in the short transverse direction are as follows: 44.8 ksi UTS, 38.1 ksi Y.S., and 10.0% elongation. Chu and Wacker's results follow the trend of lowest ductility (% elongation) in the short transverse direction.

12. Chu and Wacker also note the existence of "variations in strength and ductility from the surface to the center" of the forgings. (Chu & Wacker, Pg. 98) Table 3 is a reproduction of data from Chu and Wacker, which demonstrates the variation in

mechanical properties from the surface and center regions of a forging. The variation in mechanical properties from the surface to the center of the forging is related to the variation in deformation in the forging process. At the center of the forging, the degree of deformation is highest. In contrast, the surface of the forging underwent the least amount of deformation. Recrystallized grains first appear in regions undergoing the most severe distortion. (Brick, Pg. 82) Based on the mechanical properties of Table 3 and the micrographs provided by Chu and Wacker (see e.g., Figure 2 of the Declaration filed on July 11, 2003 in this patent application), the center of the forging consists primarily of recrystallized grains, while the surface contains a high amount of unrecrystallized grains. Chu and Wacker's results follow Brick's description of high deformation in the center region, resulting in a larger equiaxed grain structure at the center as a result of faster recrystallization in this region. In the regions containing unrecrystallized grains, *i.e.* elongated grain structure, one would expect the material to have relatively high strength and low ductility properties. In contrast, regions containing primarily recrystallized grains, *i.e.* equiaxed grain structure, one would expect the material to have a relatively low strength and high ductility. Chu and Wacker's data for a 6061-T652 forging follows the above relationship between properties and the amount of recrystallized grains, with the exception of ductility in the long transverse direction.

Table 3.

Chu and Wacker's Mechanical Property Comparison
at the Surface and Center of a 6061-T652 Forging.

Orientation	Location	UTS (ksi)	Yield Stress (ksi)	%Elongation
Longitudinal (Working Direction)	Surface	49.0	44.1	12.0
	Center	43.0	37.8	15.0
Long Transverse	Surface	49.3	43.1	14.0
	Center	45.3	39.3	11.5

13. Another property of aluminum alloys that has been shown to be highly dependent on orientation is fracture toughness. Fracture toughness is defined as the energy required to propagate a crack through a material. Mechanical properties of wrought aluminum alloys are known to be anisotropic, *i.e.*, dependent on orientation. Properties such as fracture toughness, corrosion, and fatigue are also known to be anisotropic. Typical orientations tested for wrought aluminum alloys are shown in Figure 1 (Annual Book of ASTM Standards, Volume 3.01, E 399). The first letter of the two letter code designates the direction normal to the crack plane. The second letter designates the expected direction of crack propagation.

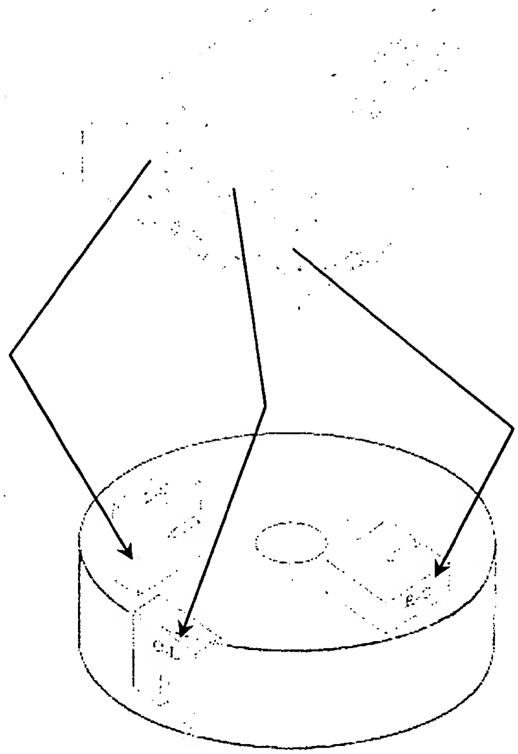


Figure 1. Typical Fracture Toughness Testing Orientations for Wrought Aluminum Sheet (top) and Hollow Cylinders (bottom).

14. The desired microstructure for improved fracture toughness properties is a uniform fine equiaxed grain structure. The goal is to create a tortuous path for crack propagation. Figures 2 and 3 illustrate the differences in orientation and how it relates to fracture toughness. As shown in Figure 2, when the direction of crack propagation is the same as the direction of maximum deformation, *i.e.* elongated grain structure, there exists little resistance to the propagation of the crack along the elongated grain structure. When the direction of crack propagation is perpendicular to the direction of maximum grain flow, *i.e.* the L-T or C-L orientations, a tortuous path exists that the crack must follow, as shown in Figure 3. Because a centrifugally cast 6061-T6 alloy microstructure consists of equiaxed grains, properties are expected to be isotropic. For the case of fracture toughness properties, a tortuous path similar to that shown in Figure 3 exists for a crack to follow.

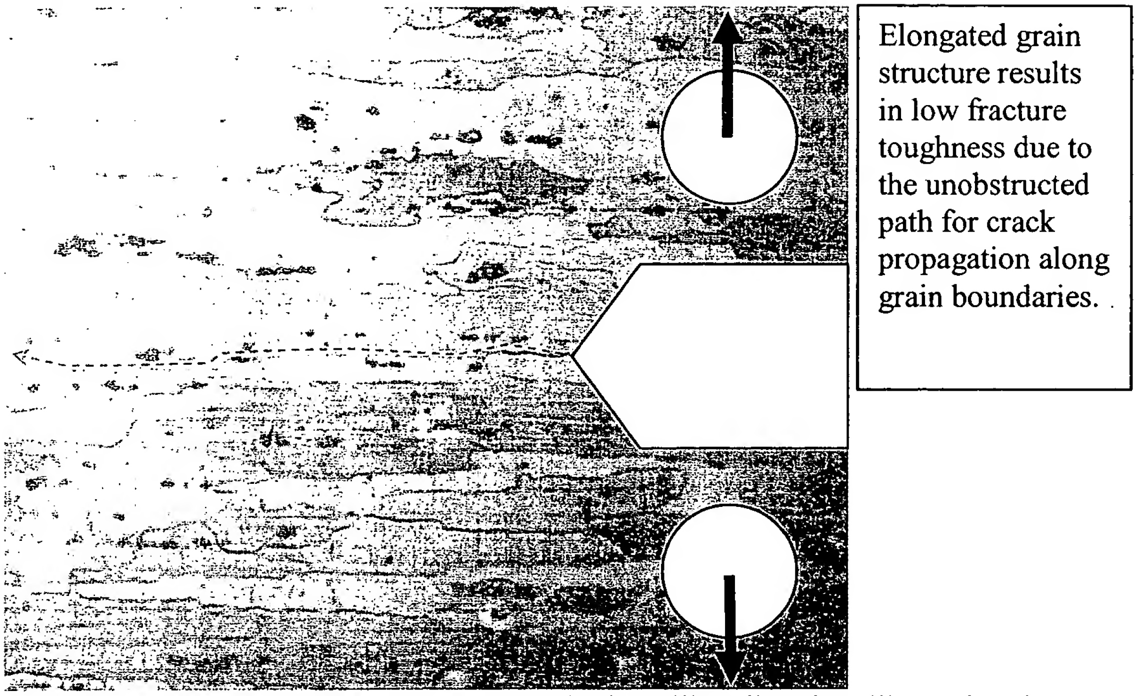


Figure 2. Microstructure of 7075 extrusion in the rolling direction, illustrating the elongated grain structure and the path for crack propagation.

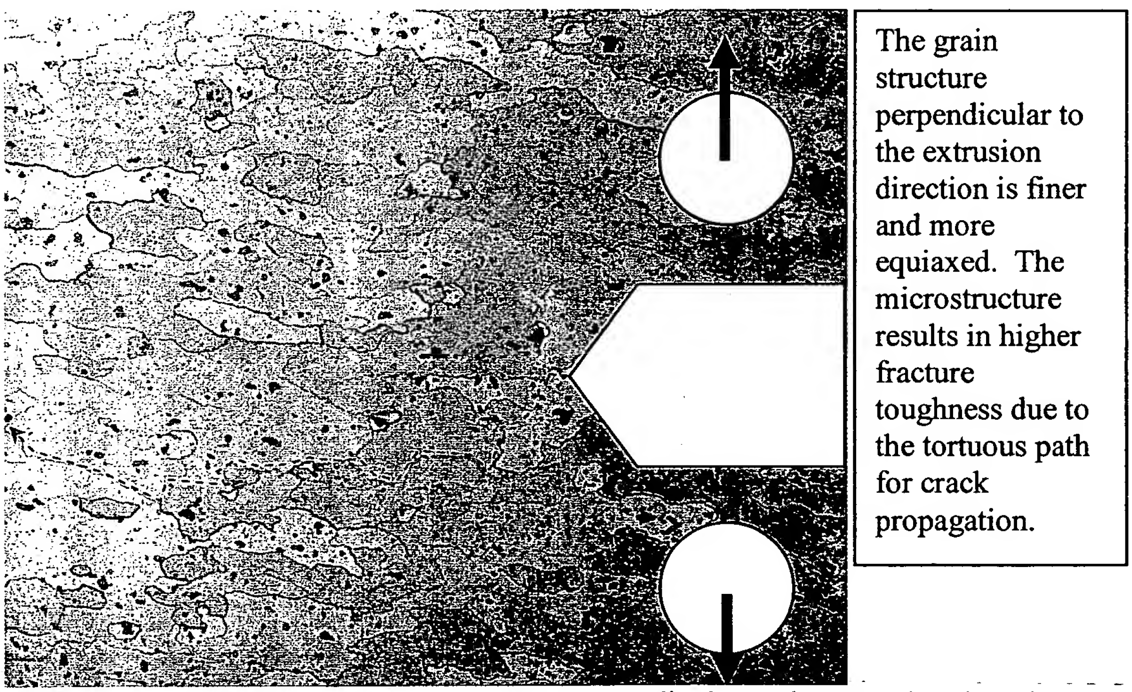


Figure 3. Microstructure of 7075 extrusion perpendicular to the extrusion direction, illustrating the fine grain structure and the tortuous path for crack propagation.

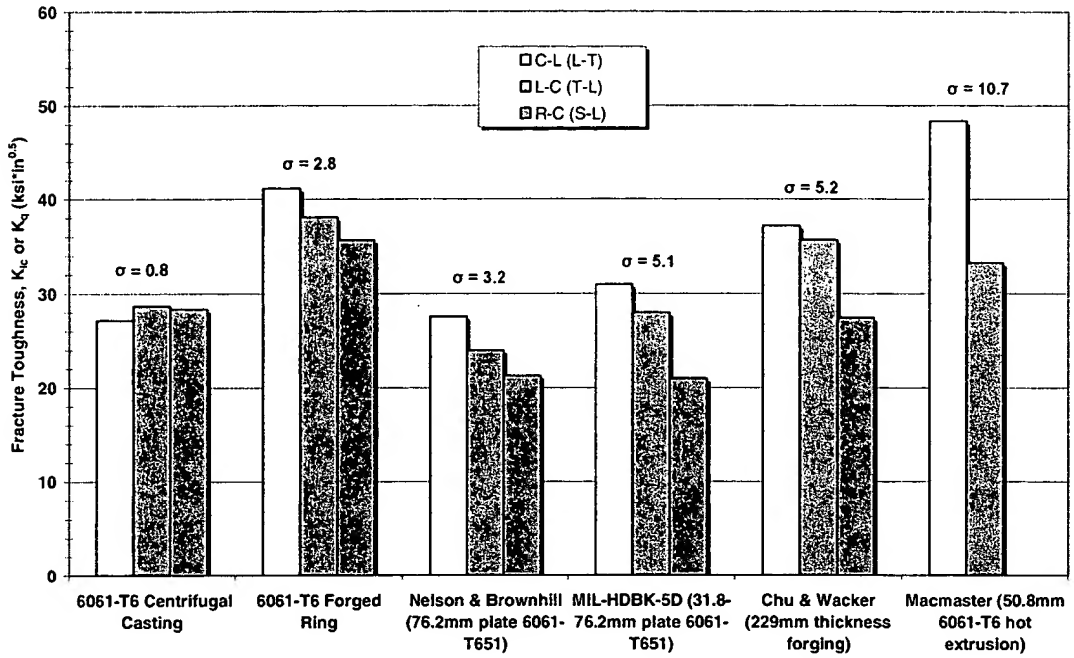
Table 4.
Fracture Toughness (K_{Ic}) Comparison of
Centrifugally Cast and Wrought 6061-T6 Aluminum

Orientation	Centrifugally Cast 6061-T6 (21" O.D. x13" I.D. x12" L) ksi*in$^{0.5}$	6061-T6 Forged Ring (21" O.D. x13" I.D. x12" L)[a] ksi*in$^{0.5}$	Nelson & Brownhill (76.2mm plate 6061-T651)[b] ksi*in$^{0.5}$	MIL-HDBK-5D (31.8-76.2mm plate 6061-T651)[b] ksi*in$^{0.5}$	Chu & Wacker (229mm thickness forging) ksi*in$^{0.5}$	Macmaster (50.8mm 6061-T6 hot extrusion) ksi*in$^{0.5}$
L-C (T-L)	28.7	38.1	24.0	28	35.7	33.3
C-L (L-T)	27.2	41.2	27.6	31	37.2	48.4
R-C (S-L)	28.4	35.7	21.3	21	27.5	Not measured
Average	28.1	38.3	24.3	26.7	33.5	40.9
Standard Deviation	0.79	2.8	3.2	5.1	5.2	10.7

[a] Forged Ring purchased from forging supplier for comparison purposes and produced in accordance with ASTM B 247.

[b] Values referenced from Yahr, G.T., "Prevention of Nonductile Fracture in 6061-T6 Aluminum Nuclear Pressure Vessels."

Figure 4. Fracture Toughness Comparison of Centrifugally Cast and Various Wrought 6061-T6 Aluminum.



15. The method used to test for isotropic fracture toughness properties was to determine the standard deviation of fracture toughness specimens tested in several orientations. As shown in Table 4 and Figure 4, the fracture toughness results of the centrifugally cast 6061-T6 for the three different orientations contains a significantly lower standard deviation compared to those of wrought products. Similar to the mechanical property results, the fracture toughness properties of the centrifugally cast 6061-T6 shown in Table 4 suggest that the material is isotropic, *i.e.* the physical properties are independent of orientation.

16. The isotropic fracture toughness properties of the centrifugally cast 6061-T6 can be attributed to the uniform equiaxed grain structure present in the microstructure, as depicted in Figures 5 and 6. Because all orientations of a centrifugally cast aluminum alloy exhibit the uniform equiaxed microstructure, one skilled in the art would expect fracture toughness properties to be substantially identical in all directions, as shown by the low standard deviation between the different fracture toughness orientations. Fracture toughness properties of various wrought 6061-T6 alloys possess high standard deviations with respect to orientation. Compared to the centrifugally cast 6061-T6, the standard

deviations for wrought products are substantially higher, approximately 3.5 to 13.5 times higher (see e.g., Table 3), illustrating their strong dependence on orientation.

Figure 5.

Centrifugally Cast 6061-T6 in the axial direction and the tortuous path for crack propagation produced by the equiaxed grain structure of the alloy (100X, Keller's Reagent); Note: The microstructure shown represents a typical structure in the crack plane for the fracture toughness test in the L-C orientation.
(R-C fracture toughness specimen-side view)

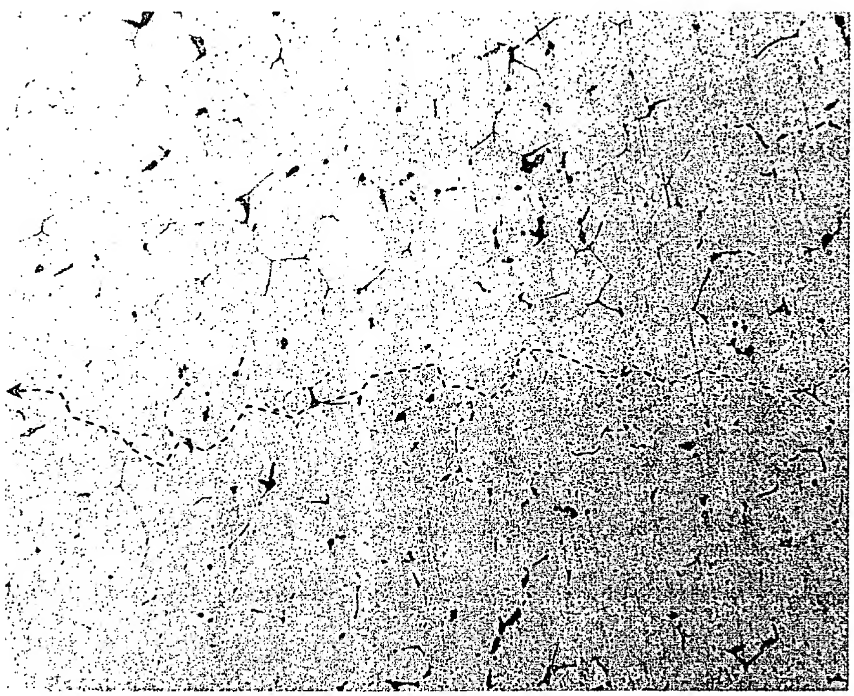
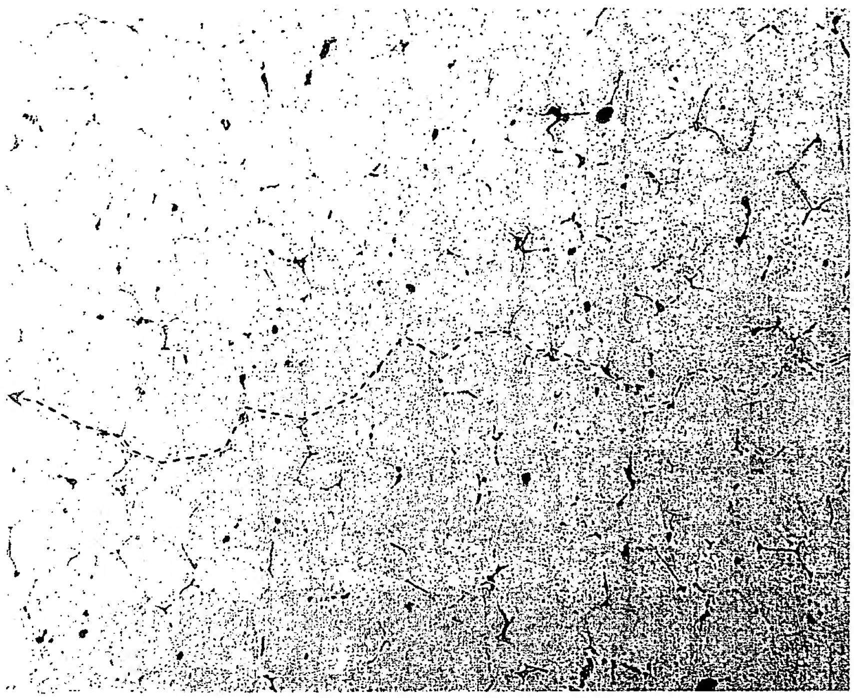


Figure 6.
Centrifugally Cast 6061-T6 in the tangential direction and the tortuous path for crack propagation produced by the equiaxed grain structure of the alloy (100X, Keller's Reagent); Note: The microstructure shown represents a typical structure in the crack plane for the fracture toughness test in the C-L orientation.



17. To further illustrate the dependence of wrought product properties on orientation, one can associate fracture toughness results to microstructures. Figures 7 through 9 illustrate the relationship between microstructure and fracture toughness in a wrought 6061-T6 forging prepared according to ASTM B 247 with dimensions of 21" O.D. x13" I.D. x12" L. Figure 7 represents a microstructure typical of the crack plane found in a fracture toughness specimen in the R-C orientation. Because crack propagation in the R-C orientation was with the flow of grains, the crack path was the least tortuous and the fracture toughness was the lowest with a value of 35.7 ksi*in$^{0.5}$. In Figure 8, the microstructure of the forged material in the axial direction appears more equiaxed and the crack path more tortuous. Fracture toughness in the L-C orientation was 38.1 ksi*in$^{0.5}$, slightly higher than that of the R-C orientation. The most tortuous crack path was found in the tangential direction, Figure 9, where the direction of crack propagation was

perpendicular to the direction of the most elongated grains. Fracture toughness in this orientation was the highest with a value of 41.2 ksi*in$^{0.5}$. For the different orientations within the wrought 6061-T6 forging, the order of fracture toughness from lowest to highest is as follows: R-C, L-C, and C-L.

Figure 7.
Wrought 6061-T6 forging in the axial direction, L-C crack plane (100X, Keller's Reagent). Red line represents a typical crack propagation pattern for a fracture toughness test performed in the L-C orientation.
K_{Ic} = 38.1 ksi*in$^{0.5}$.

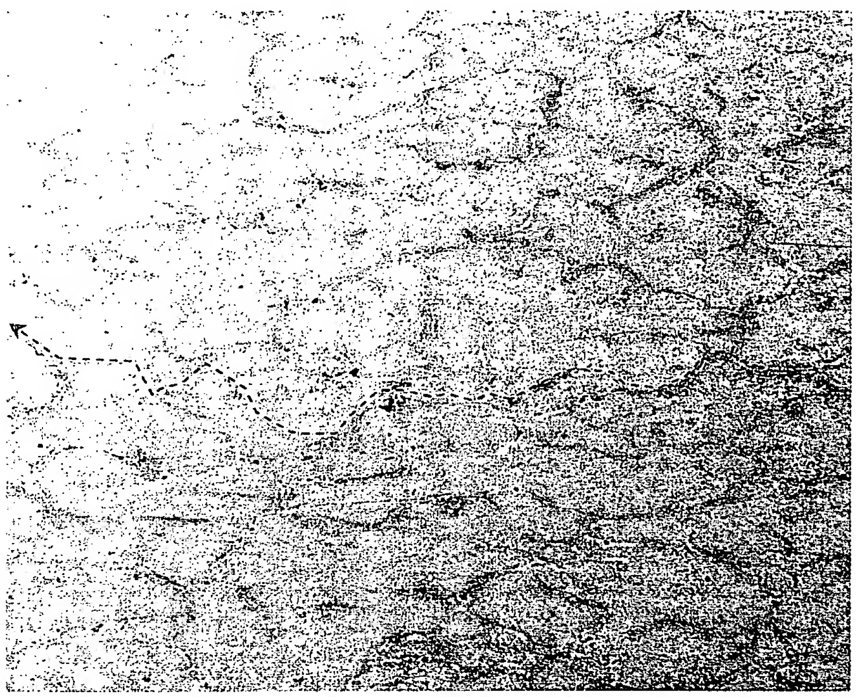


Figure 8.
Wrought 6061-T6 forging in the radial direction, R-C crack plane (100X, Keller's Reagent). Red line represents a typical crack propagation pattern for a fracture toughness test performed in the R-C orientation.
$K_{Ic} = 35.7$ ksi*in$^{0.5}$.

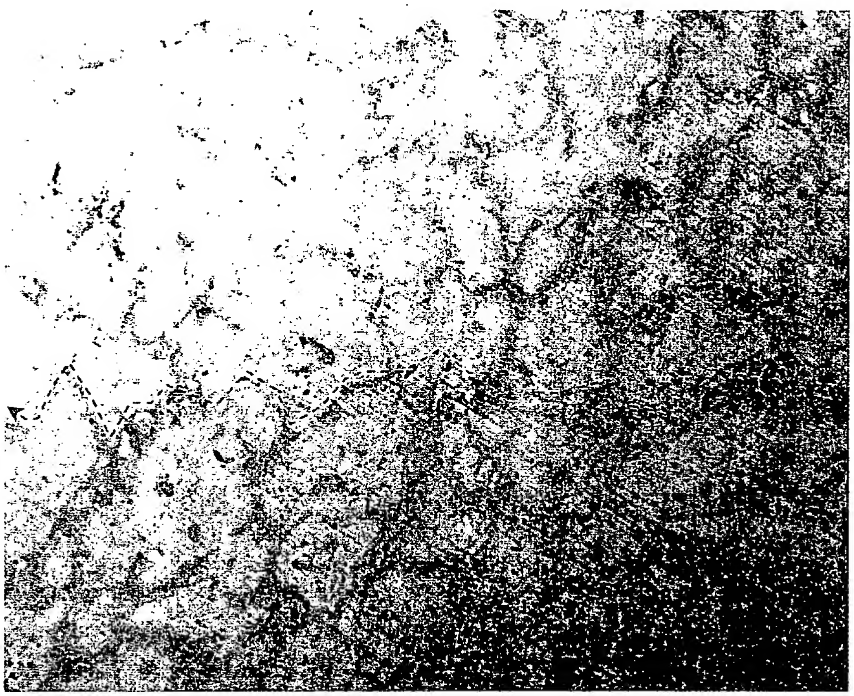
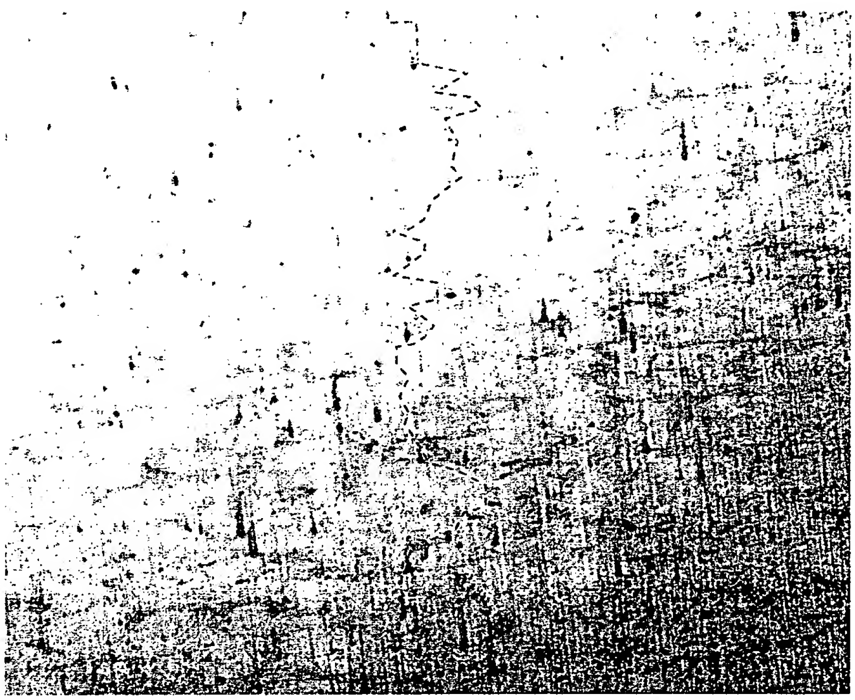


Figure 9.
Wrought 6061-T6 forging in the tangential direction, C-L crack plane, showing the elongated grain structure. (100X, Keller's Reagent) Red line represents a typical crack propagation pattern for a fracture toughness test performed in the C-L orientation. $K_{Ic} = 41.2$ ksi*in$^{0.5}$.



18. The ranking of the fracture toughness of the wrought 6061-T6 forging also holds for other various forms of wrought 6061-T6. Fracture toughness values for wrought plate and extrusions shown in Table 3 and Figure 4 from lowest to highest are as follows: R-C, L-C, and C-L. The only material that did not follow the above trend was the centrifugally cast 6061-T6, where the fracture toughness values for all three orientations were substantially identical.

19. An argument could be made that a completely recrystallized grain structure would be similar to that of a centrifugally cast material. The microstructural development of wrought aluminum consists of three stages: recovery, recrystallization, and grain growth. Complete recrystallization is difficult to define since there does not exist a clear division

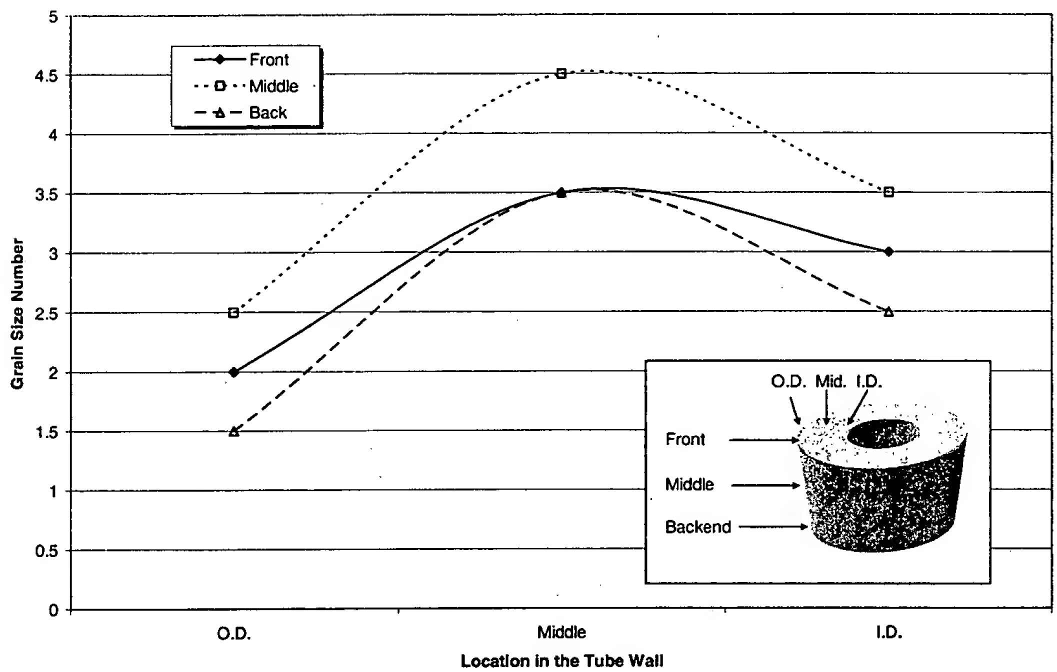
between the stages of recrystallization and grain growth. Typically, complete recrystallization is defined as a percentage of the material that has recrystallized, for example 95% complete. (See, Brick, Pg. 82)

20. Nucleation of recrystallized grains occurs at regions that underwent the most severe deformation. Since deformation is not uniform in a worked piece, recrystallization is dependent on location within the wrought product. A recrystallized grain structure differs from that of a centrifugally cast grain structure based on (1) non-uniform deformation in the wrought process and (2) non-uniform nucleation of recrystallized grains.

21. Because of the non-uniform deformation, one would expect to find regions within the work-piece in different stages of recrystallization. The only method of obtaining a <u>uniform</u> recrystallized grain structure is to have <u>uniform</u> <u>deformation</u> in the work piece. In practical terms, obtaining uniform deformation in a hot-working process is essentially impossible due to factors, such as temperature gradients within the piece, difference in temperature between the work-piece and the tooling, and friction between the work-piece and the tooling. The extruded and drawn 6XXX KDS4 alloy described in Shaffer *et al.* (U.S. Patent No. 6,248,189) demonstrates the dependence of grain size on location (see Table 2 of Shaffer and Figure 10). Shaffer's material behaves similar to the description given by Dieter, where deformation is greatest at the surface. Based on the description of the processing steps and the grain size analysis given by Shaffer, one would expect the highest deformation to occur at the surfaces of the cross-section, *i.e.*, the O.D. and the I.D. of the extrusion. In contrast, the center of the extrusion would have undergone the least amount of deformation. Because the surface of the cross-section underwent the highest degree of deformation, initiation points for recrystallization would be more numerous at the surface regions as compared to at the center of the extrusion. Upon completion of Shaffer's process, the grain size data (see Table 2 of Shaffer) suggests that the surface regions of the extrusion, O.D. and I.D., have recrystallized, while the middle region of the extrusion remains unrecrystallized. If the material had remained at the recrystallization temperature for a longer period, the surface regions would eventually

begin to undergo grain growth, but the center region would be expected to still be in an initial stage of recrystallization.

Figure 10. Dependence of Grain Size on Location within the Wall of an Extruded and Drawn 6XXX (KDS4) Alloy Produced by Shaffer et al. (US Patent No. 6248189 B1).



22. To further illustrate the differences in microstructures that can occur during the hot working process, Figures 11 and 12 show the microstructures of an extruded 6XXX alloy. Figure 11 shows an extrusion with a rectangular cross section. The surface of the extrusion underwent a greater degree of deformation than the middle of the extrusion. The resulting macrostructure of the surface of the extrusion shows large grains, representative of the grain growth stage of recrystallization. The center of the extrusion, however, consists of unrecrystallized grains. In the macrostructure of an extruded aluminum alloy piece (see, e.g., Figure 11), the unrecrystallized grains appear as fine grains in this orientation, but a longitudinal macrostructure would show an elongated grain structure. Figure 12 shows a microstructure of the near surface region of an extruded tube. The microstructure consists of large grains at the surface and unrecrystallized elongated grains near the center of the extrusion. In summary, the

working process and the heat loss associated with hot working can have a dramatic and non-uniform effect on the microstructure of a work-piece. Due to non-uniform deformation resulting from the working process, differences in microstructure will exist within the work-piece.

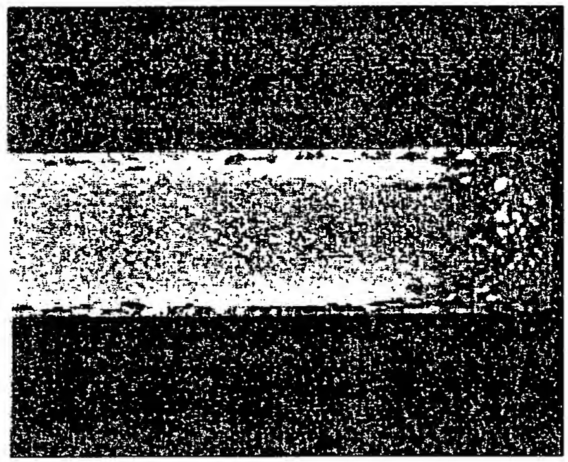


Figure 11.
The Cross-section of a 6XXX Extrusion Illustrating the Difference in Macrostructure from the Surface to the Center of the Extrusion. Grains near the Surface have Underwent Grain Growth, while Grains in the Middle Remain Unrecrystallized (ASM Handbook, Vol. 9, Figure 62, Pg. 367).

Figure 12.
Microstructure of a 6XXX Extrusion near the Surface, Illustrating the Unrecrystallized Grains at the center of the Extrusion and the Grains at the Surface that underwent Grain Growth.
(ASM Handbook, Vol. 9, Figure 64, Pg. 367)

23. Various forms of wrought aluminum have been shown to have anisotropic mechanical and fracture toughness properties. Conversely, centrifugally cast 6061-T6 aluminum has been shown to exhibit isotropic mechanical and fracture toughness properties. The isotropic nature of the aluminum centrifugal casting can be attributed to the fine equiaxed grain structure present in the microstructure.

24. Recrystallization of a wrought product can result in a fine equiaxed grain structure. Due to non-uniform deformation of wrought aluminum, the grain structure in wrought and recrystallized aluminum alloy pieces will be non-uniform, *i.e.*, a structure containing regions of different grain size, irrespective of the aluminum alloy composition. If an aluminum alloy piece is fully annealed (O-temper) to ideally achieve an equiaxed grain structure, the strength properties of the piece are expected to be significantly different from that of the alloy in a –T6 temper. It should also be noted that even though an aluminum alloy can be annealed to achieve an equiaxed grain structure,

the uniformity of the grain structure is dependent on the uniformity of previous deformation. Therefore, as one skilled in the metallurgical art, it is my opinion that wrought alloys of 2000, 4000, 6000, 7000 and 8000 series, even if fully recrystallized, will have non-uniform and/or non-equiaxed grain structure. Moreover, fully annealed alloys of this type will not possess strength properties equivalent to the cast alloys according to the invention of the above-identified application.

25. In this declaration, I referred to various technical references by the name of the first author and/or title. The citations for these references are as follows.

1. ASM Handbook Vol. 9 Metallography and Microstructures.

2. Brick, R.M, Pense, A.W. and Gordon, R.B., Structure and Properties of Engineering Materials, 4th Ed., McGraw–Hill Publishing Company, New York. 1977, pages 87-99.

3. Chu, H.P. and Wacker, G.A., "Fracture Toughness and Stress Corrosion Properties of Aluminum Hand Forgings," 1972, *Journal of Materials*, JMLSA, Vol. 7, No. 1, March, pp. 95-99.

4. Dieter, G.E.. Mechanical Metallurgy, 3rd Ed. McGraw–Hill Publishing Company, New York, 1986, pages 526-529.

5. Hatch, J.E.. Aluminum:Properties and Physical Metallurgy. ASM International. 1984. 424 pages.

6. MacMaster, F.J., Chan, K.S., Bergsma, S.C., and Kássner, M.E. "Aluminum Alloy 6069 part II: Fracture Toughness of 6061-T6 and 6069-T6." *Materials Science & Engineering A289*, (2000), pgs. 54-59.

7. Shaffer, T.J. and Diggs, J.E.. "Aluminum Alloy Useful for Driveshaft Assemblies and Method of Manufacturing Extruded Tube of such Alloy." U.S. Patent No. 6,248,189 B1. June 19, 2001.

8. Yahr, G.T., Transactions of the ASME, vol. 119, pp. 150-156 (May, 1997).

To the extent that these references have not been previously submitted to the PTO, they are included as part of an Information Disclosure Statement submitted concurrently herewith.

26. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful, false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title XVIII of the United States Code and that such willful, false statements may jeopardize the validity of the above-identified application or any patent resulting therefrom.

By Arvin Montes
Arvin Montes, Ph.D.

Date: 10/30/2003